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Second Interim Report on the Computation of Helicopter Rotor Wake Geometry

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M.P. Scully

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ASRL TR 150-2

AEROELASTIC AND STRUCTURES RESEARCH LABORATORY
MASSACHUSETTS INSTITUTE OF TECHNOLOGY
CAMBRIDGE, MASS

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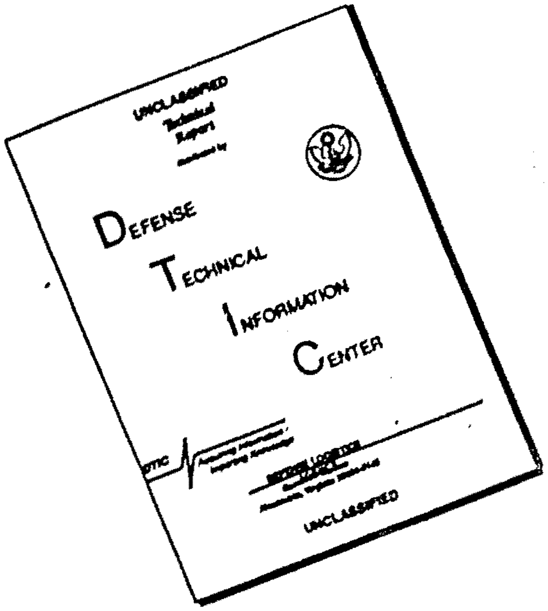

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Aeroelastic and Structures Research Laboratory
Department of Aeronautics and Astronautics
Massachusetts Institute of Technology
Cambridge, Massachusetts 02139

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Introduction

The following discussion repeats that reported in Ref. 2. The wake of a helicopter rotor consists of a relatively concentrated tip vortex generated by the rapid decrease in bound circulation at the tip of the rotor blade and distributed vortex sheets generated by spanwise variation of the bound circulation over the inboard portion of the blade (the inboard trailing wake) and by azimuthal variations of the bound vorticity (the shed wake). The tip vortex, because of its concentration, is best represented by a vortex line, with a finite vortex core where viscous effects dominate, and is responsible for the sharp peaks in the rotor airloads distribution. Thus accurate geometry is much more important for the tip vortex than for the rest of the wake and effort has been concentrated on the accurate and efficient computation of the tip vortex geometry.

The computation of the tip vortex geometry involves the integration over time of the induced velocity at various points on the tip vortex. Since the computed tip vortex geometry changes as the computation proceeds (converging on the actual geometry), the induced velocities must be recomputed (updated) periodically to account for these changes. Since most of the computational effort goes into computing induced velocities, finding techniques to minimize the amount of updating required is very important.

Any point P on the tip vortex can be identified by its azimuth and its age (time elapsed since point P was trailed from the rotor) at any instant. Tip vortex geometry computations generally proceed by computing the geometry of every azimuth at age $\Delta\phi$ (typically $\Delta\phi = 15°$), then at $2\Delta\phi$, $3\Delta\phi$, and so on up to 4π or 6π. This computation is repeated iteratively until satisfactory convergence is achieved. In Reference 1, the induced velocities used to compute the geometry were updated every $n\Delta\phi$ in age (typically $n = 6$) at every azimuth. At every age δ at which induced velocities were updated the geometry for ages from $\Delta\phi$ to δ and at all azimuths was recomputed to reflect the updated induced velocities. A technique for updating the induced velocity and

geometry at each azimuth independent of the other azimuths based on the amount of distortion accumulated was developed under contract N00019-67-C-0236 and will be described in Reference 2. This method of independent updating did not result in the desired reduction in computational effort and was abandoned for work on more promising techniques under contract N00019-68-C-0150, as described below.

New Work

The following discusses work beyond that reported in Reference 4. The basic idea was to use an updating technique similar to that of Reference 1 where the induced velocities and geometry at all azimuths were updated every $n\Delta\phi$ in age, but to update only the induced velocities generated by part of the wake (the near wake) and leave the induced velocities generated by the rest of the wake (the far wake) fixed during each iteration. The far wake must be chosen to be so far away from the point P at which induced velocities are computed that normal changes in the computed wake geometry are negligible by comparison. On the other hand, the near wake should be minimized to reduce the computational effort required.

The induced velocity generated by the entire wake, both near and far, are computed once at the beginning of each iteration at every point P on the tip vortex at which the wake geometry is to be computed. Thus the ideal way to divide the wake is to define the near wake relative to any point P to include any element of the wake model which generates an induced velocity at point P greater than V_m, an input parameter to be determined by experiment. Since there can be up to 1825 points P and up to 1750 elements of the wake model which generate induced velocity at any point P about 3×10^6 storage locations would be needed to store such a map of the near and far wakes. Since the available computer facility has about 4×10^5 words of core storage, this method of defining the near wake was temporarily abandoned and various attempts were made to develop a simple a priori definition of the near wake. These included defining all of the tip

vortex to be the near wake or defining all of the wake within ψ_n (typically $\pi/2$ or π) in azimuth of any point P and on the same tip vortex as that point P to be the near wake. None of these simple definitions of the near wake gave acceptable results compared to the normal computation without near and far wakes.

At this point in time, a review copy of the paper which eventually became Reference 3 was received and it reported the very successful application of the ideal definition of the near wake described above. Since the core storage needed to use this definition of the near wake was not available at M.I.T., it was decided to attempt to develop an approximation to the ideal definition of the near wake which would minimize storage requirements. The first approximation involved gathering all of the wake elements at each azimuth and age combination on the wake of each blade into a unit. Each unit included an element of the tip vortex, an element of the inboard trailing vortex sheet, and an element or elements of the shed wake. The near wake relative to each point P on the tip vortex was redefined to include every unit which generated a total induced velocity at point P greater than V_m.

If unlimited core storage were available, the easiest thing to do would be to store the induced velocity generated by each unit at each point P on the tip vortex in a separate storage location. The computation of the updated induced velocity at each point P on the tip vortex would then have proceeded by examining induced velocity at point P generated by each unit. If the induced velocity was greater than V_m it would be recomputed, otherwise the old induced velocity would simply be added on to the total. Since the core storage required for this was not available, the total induced velocity at each point P (each different azimuth and age) on the tip vortex generated by the far wake (consisting of all units generating an induced velocity less than V_m at point P) was computed once at the beginning of each iteration and stored.

A map of the near and far wakes was also needed since this

information was no longer contained in the induced velocity information. Instead of storing a different map of the near and far wakes for each different point P (each different azimuth and age combination) on the tip vortex, a different map was stored for each different azimuth on the wake of each blade. This saved storage since there are fewer blades than different ages. The maps were stored in terms of the time elapsed between the instant when the element of the tip vortex at point P was trailed by the rotor and the instant when the unit of wake which is to be classified as near or far wake relative to point P was shed by the rotor. To save storage only the elapsed times for the transitions between near and far wake were stored instead of storing the elapsed times for all of the units in the near wake.

The net result of the approximations described above was to reduce the core storage required to use the near and far wake model from about 3×10^6 words to about 1×10^4 words. This made it practical to develop a new computer program using the near and far wake approximation. The large reduction in the amount of computation involved in updating, due to the use of the near and far wake approximation, allowed the basic updating scheme of Reference 1 to be modified for greater accuracy without resulting in prohibitive amounts of computation. In Reference 1, the updating of the induced velocity and the wake geometry at any age δ and azimuth ψ was done by recomputing the induced velocity generated by the entire wake at age zero and azimuth ψ and then adding on the induced velocity generated at azimuth ψ by each additional unit of wake that was created as the age was increased in steps of $\Delta\phi$ up to δ. This gave a time history of the induced velocity at azimuth ψ for all ages between zero and δ in $\Delta\phi$ steps which was integrated to get the corresponding time history of wake geometry. To improve the accuracy of the computation, this updating technique was modified by recomputing the induced velocity generated by the entire wake at azimuth ψ and age 0, then adding on the induced velocity generated at azimuth ψ by each additional unit of wake created as the age was increased in steps of

$\Delta\phi$ up to $(n-1)\Delta\phi$, then recomputing the induced velocity generated by the entire wake at azimuth ψ and age $n\Delta\phi$, and so on up to age δ. Despite the large amount of additional recomputation of the induced velocities involved in this improved updating technique, the new wake geometry computer program developed using it plus the near and far wake approximation proved to be substantially faster than the program described in Reference 1.

The new wake geometry program was tested using various values V_m and n. Preliminary results indicate $V_m = 0.03$ and $n = 8$ give good results but more testing is necessary. When compared with the wake geometry program described in Reference 1, the new wake geometry program was not only faster but gave somewhat different results. In theory, the results from the new program should be more accurate than those obtained in Reference 1, but uncertainties in the experimental wake geometry data from smoke tests prevented confirmation of this. Work is continuing under contract N00019-69-C-0219 to refine the experimental data to provide a reliable check on the theory and to refine the new wake geometry program. This work, including a more detailed description of the new wake geometry program, will be reported in Reference 2.

In parallel with the development of the new wake geometry program, work continued on the use of vortex sheets to represent the inboard trailing wake and the shed wake in the wake model. This is desirable because, as discussed in the Introduction, the inboard trailing wake and the shed wake are distributed vortex sheets in the real world. When vortex lines are used to represent these distributed vortex sheets, artificial peaks are introduced in the induced velocity distribution and it is a matter of chance whether or not a point P on the tip vortex at which induced velocities are computed happens to lie on the positive or on the negative induced velocity side of such a peak. The use of vortex sheets eliminates this problem.

A closed form integration of the Biot Savart relation for induced velocities over a rectangular, planar vortex sheet has been

developed similar to that developed for a straight vortex line segment. The wake model of the inboard trailing wake and the shed wake can therefore be constructed out of a series of rectangular, planar vortex sheets just as the wake model for the concentrated tip vortex is made up of straight vortex line segments (see Reference 1). Breaking the wake up into planar rectangles adds artificial edges and their associated singularity. Since the exact choice of the boundaries of the rectangles is arbitrary, they can be chosen to avoid the singularity at the edges.

Under contract N00019-68-C-0150, criteria were developed for avoiding the edge singularity. In addition, the subroutine used to compute the induced velocity generated by a planar, rectangular vortex sheet was improved so that it now takes 2.5 to 3 times as long as the corresponding computation for a straight vortex line segment compared to the 5 to 6 times as long required by the original subroutine. A preliminary trial of the vortex sheet wake model was made using the new wake geometry program. The results were promising but the computation required almost 3 times as long as a similar computation using the vortex line model. Further development is needed to reduce the computation required and to improve convergence. In addition, a better experimental data base is needed to properly evaluate the results. Work on these is proceeding under contract N00019-69-C-0219 and will be reported in Reference 2 along with a detailed description of the computation of induced velocities and the criteria for avoiding the edge singularity.

References

1. Scully, M.P. A Method of Computing Helicopter Vortex Wake Distortion. Massachusetts Institute of Technology, Aeroelastic and Structures Research Laboratory, ASRL TR 138-1, June 1967.

2. Scully, M.P. Computation of Helicopter Rotor Wake Geometry and its Influence on Rotor Harmonic Airloads. Massachusetts Institute of Technology, Aeroelastic and Structures Research Laboratory, ASRL TR 157-1 (to be published).

3. Landgrebe, A.T. An Analytical Method for Predicting Rotor Wake Geometry. AIAA-AHS-VTOL Research Design and Operations Meeting, Atlanta, Georgia, Feb. 17-19, 1969, AIAA Paper 69-196.

4. Scully, M.P. Interim Report on the Computation of Helicopter Rotor Wake Geometry. Massachusetts Institute of Technology, Aeroelastic and Structures Research Laboratory, ASRL TR 145-2, Dec. 1968.